Improving Post-Hurricane Katrina Forest Management with MODIS Time Series Products

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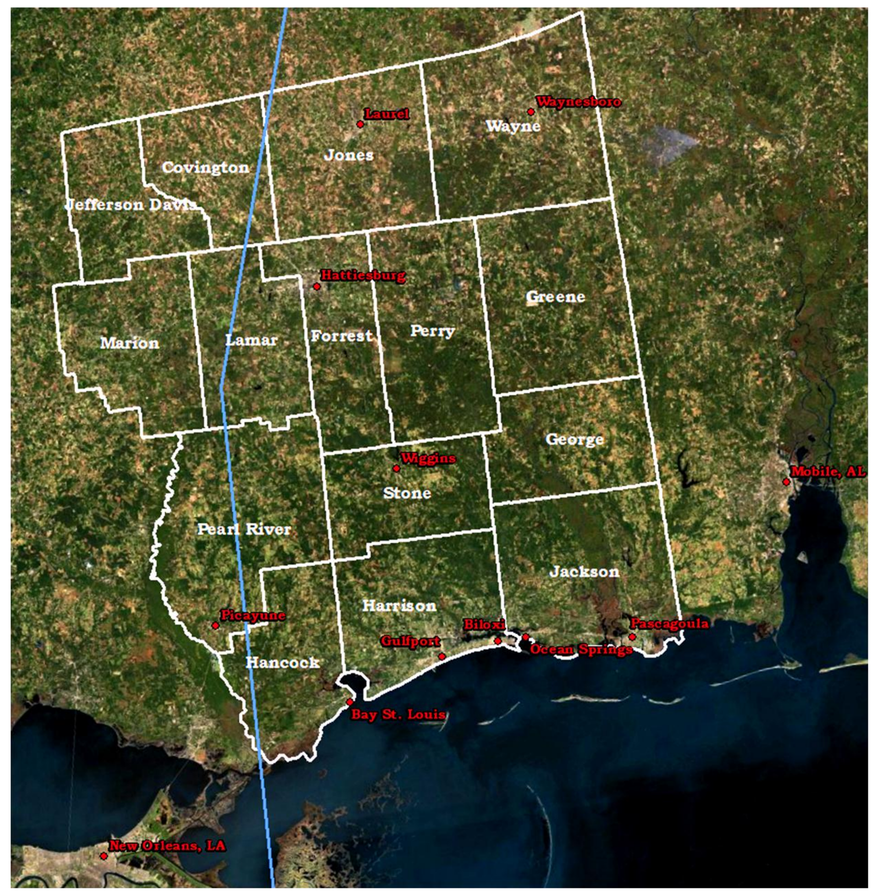

Figure 1 - Study Area: The 15 Mississippi counties of MIFI's Southeast Inventory District. The blue line is Hurricane Katrina's track on August 29, 2005.

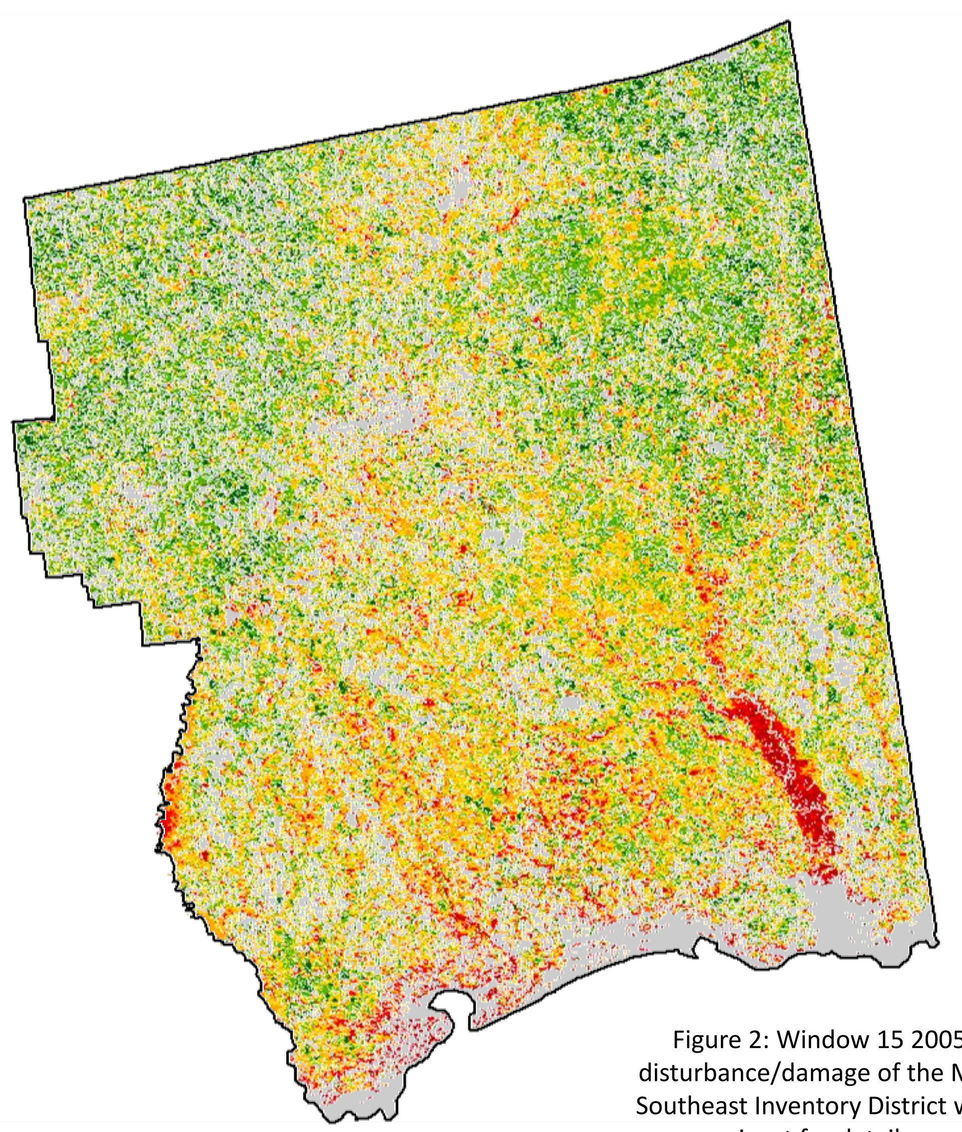

Figure 2: Window 15 2005 disturbance/damage of the MIFI Southeast Inventory District with inset for detail

	Non-forested Area	
Class 1	>= 0% (no residual loss of forest canopy greenness)	
Class 2	0% to -5% (low residual loss of forest canopy greenness)	
Class 3	-5% to -10% residual loss of forest canopy greenness	
Class 4	-10% to -15% residual loss of forest canopy greenness	
Class 5	-15% to -20% residual loss of forest canopy greenness	
Class 6	<-20% (very high residual loss in forest canopy greenness	

ABSTRACT

Hurricane damage to forests can be severe, causing millions of dollars of timber damage and loss. To help mitigate loss, state agencies require information on location, intensity, and extent of damaged forests. NASA's MODerate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) time series data products offers a potential means for state agencies to monitor hurricane-induced forest damage and recovery across a broad region. In response, a project was conducted to produce and assess 250 meter forest disturbance and recovery maps for areas in southern Mississippi impacted by Hurricane Katrina. The products and capabilities from the project were compiled to aid work of the Mississippi Institute for Forest Inventory (MIFI).

A series of NDVI change detection products were computed to assess hurricane induced damage and recovery. Hurricane-induced forest damage maps were derived by computing percent change between MODIS MOD13 16-day composited NDVI pre-hurricane "baseline" products (2003 and 2004) and post-hurricane NDVI products (2005). Recovery products were then computed in which post storm 2006, 2007, 2008 and 2009 NDVI data was each singularly compared to the historical baseline NDVI. All percent NDVI change considered the 16-day composite period of August 29 to September 13 for each year in the study (Table 1). This provided percent change in the maximum NDVI for the 2 week period just after the hurricane event and for each subsequent anniversary through 2009, resulting in forest disturbance products for 2005 and recovery products for the following 4 years.

These disturbance and recovery products were produced for the Mississippi Institute for Forest Inventory's (MIFI) Southeast Inventory District (Figure 1) and also for the entire hurricane impact zone. MIFI forest inventory products were used as ground truth information for the project. Each NDVI percent change product was classified into 6 categories of forest disturbance intensity. Stand age and stand type raster data, also provided by MIFI, were used along with the forest disturbance/recovery products to create forest damage stratification products integrating 3 stand type classes, 6 stand age classes, and 6 forest disturbance intensity classes. This stratification product will be used to aid MIFI timber inventory planning and to prepare for damage assessments due to future hurricane events. Validation of MODIS percent NDVI change products was performed by comparing the MODIS percent NDVI change products to those from Landsat data for the same time and MIFI inventory district area.

BACKGROUND

- Hurricane Katrina was one of the most powerful and deadliest storm systems ever to make landfall in the United States.
- It was also the costliest in U.S. history, causing estimated damages in excess of $108 billion.[1]
- After entering the Gulf of Mexico, Hurricane Katrina strengthened and made landfall on August 29, 2005:
  - Sustained wind speeds topping 175 mph and record storm surge[1]
  - Widespread destruction to property and over 1800 fatalities[1]
- The storm also severely impacted the forested lands along the northern Gulf of Mexico, especially in Mississippi. This impact was a large blow to the overall economy of the state:
  - The forest products industry in Mississippi generates over $17 billion of economic impact and contributes to 8.3% of all jobs in the state[2]
  - Timber is an important agricultural crop in the local economy of virtually every Mississippi County outside the Delta[2]
  - In any year, timber will be among the top three most valuable agricultural crops in 65 to 70 counties out of 82 total counties in Mississippi[2]
  - Forested lands of Mississippi are also vital habitats for indigenous species and important sources of clean water
- With an important natural resource so negatively impacted, this NASA funded program sought to explore the utility of MODIS time series data products to quantify the impact of Hurricane Katrina on coastal forests and provide more cost effective ways to determine the impact of tropical cyclones to affected timber industries.
- MODIS time series data products are seen as a low-cost alternative to on-demand high resolution optical sensor data collections and ground survey studies .
- Identification of heavily impacted forest areas can precipitate more directed and efficient ground sampling investigations.
- MODIS offers a source of high temporal resolution data for monitoring vegetation changes at regional scales.[3]
- Phenological data trending provides rapid identification of dissimilarities between successive time steps (in this case annual).

Window	1	2	3	4	5	6	7	8	9	10	11
Time Period	Jan 17 to Feb 1	Feb 2 to Feb 17	Feb 18 to Mar 5	Mar 6 to Mar 21	Mar 22 to Apr 6	Apr 7 to Apr 22	Apr 23 to May 8	May 9 to May 24	May 25 to Jun 9	Jun 10 to Jun 25	Jun 26 to Jul 11
Window	12	13	14	15	16	17	18	19	20	21	22
Time Period	Jul 12 to Jul 27	Jul 28 to Aug 12	Aug 13 to Aug 28	Aug 29 to Sep 13	Sep 14 to Sep 29	Sep 30 to Oct 14	Oct 15 to Oct 30	Oct 31 to Nov 15	Nov 16 to Dec 1	Dec 2 to Dec 17	Dec 18 to Jan 2

Table 1: Table of 16-day "Window" time periods

REFERENCES

1. Knabb, R., J. Rhome, D. Brown; 2006; Tropical Cyclone Report: Hurricane Katrina, *National Hurricane Center;* pp.43
2. Henderson, J.E., I.A. Munn, G. Perez-Verdin, D.L. Grebner; 2008; Forestry in Mississippi: The Impact of the Forest Products Industry on the Post-Katrina Mississippi Economy—an Input-Output Analysis. Forest and Wildlife Research Center, Research Bulletin FO374, Mississippi State University. pp.31
3. Jin, S., S. Sader; 2005; MODIS Time-Series Imagery for Forest Disturbance Detection and Quantification of Patch Size Effects; *Remote Sensing of Environment*; **99**; 462-470

METHODOLOGY

- MODIS MOD13 Normalized Difference Vegetation Index (NDVI) 16-day temporal composite data were used to generate forest disturbance/damage products.
- NDVI mean-compositing provides the benefit of eliminating cloud cover found in daily images as well as mitigating spectral noise.
- Focused on annual comparisons with the specific 16-day "Window" defined by the dates August 29 to September 13 because it includes the dates immediately after the hurricane event in 2005. This period is referred to as Window 15 (see Table 1).
- Disturbance/damage products were generated by calculating normalized percent NDVI change from pre-Katrina dates (baseline) to post-Katrina dates, each time comparing the same annual Window.
- Pre-Katrina NDVI is defined as the maximum NDVI value for the years 2003 and 2004. Normalized percentage change was calculated thus:
  - % NDVI Change(Window 15, 2005) = (NDVI Value (Window 15, 2005) – Max NDVI Value (Window 15, 2003-2004)/Max NDVI Value (Window 15, 2003-2004)) * 100
- Developed model routines with Erdas IMAGINE's Spatial Modeler. These models generated the disturbance/damage products. The steps taken in this model were:
  - Calculate percent NDVI change between pre-Katrina and post-Katrina dates
  - Mask out non-forested lands using MIFI's Forest Type land cover assessment products
  - Mask out pre-Katrina clear cuts (based on 2003-2004 NDVI change product)
  - Classify the resulting values into a 6-class categorization with each class representing differing degrees of NDVI change (See the legends in Figure 2 or Figure 3 for specific damage class parameters)
- Developed a color table for the 6 classes which was used for all disturbance/damage products.
- Initial forest disturbance/damage products evaluated the change between pre-Katrina (2003-2004) and immediately post-Katrina (2005) dates.
- Generated Disturbance/damage products for different 16-day composite windows with special focus placed on the August 29 to September 13 composite window (Window 15).
- Created computer code to automatically cycle through multiple windows consecutively.
- Areas which suffered no residual loss of forest canopy greenness (Class 1 - positive NDVI change) were excluded from subsequent calculations by use of a "disturbance mask" to limit annual evaluations to only areas that were identified as disturbed/damaged as a result of the hurricane event.
- Figure 2 is a map of the disturbance/damage map for Window 15 for the year 2005 over MIFI's Southeast Inventory District.

RESULTS

- The immediate post storm change product shows evident regional impacts to forests (Figure 2) with the greatest negative NDVI percent changes in coastal and bottomland hardwood forests. Severe NDVI drops were noted in storm surge impacted forests. As expected, the areas closest to the coast tended to show more severe NDVI drops than areas further from the shoreline. NDVI drops occurred in inland forests where sustained winds were responsible for structural damage to the crowns of trees as well as blow down and sheer damage; these effects are noticeable across the entire MIFI southeast inventory district.
- Subsequent annual evaluations through 2009 show a gradient of recovery in terms of NDVI values. Although the full extent of forest damage and recovery may only be partially measured by NDVI, is shown a useful measurement for disturbance on the ground.
- The extent of the hurricane disturbance and recovery, as measured by NDVI, is shown in Figure 3. The latter shows a side-by-side comparison of the NDVI changes from 2005 through 2009. All of the change images are comparisons of Window 15 for the indicated year compared to Window 15 of the baseline (refer to Table 1).
- Comparing the annual change products, one can observe the overall improvement of forest canopy greenness throughout the study period starting in 2006. At that time, new patches of highly negative NDVI change (damage classes 5 and 6) became evident. Many of these areas were the result of timber salvage clear-cutting in the initial year following the storm damage. The effects of this clear cutting can be seen throughout the subsequent years.
- The heavy damage to bottomland hardwood areas showed marked improvement in observed canopy NDVI each year while other forests close to the coast recovered more gradually.
- Graphs were computed which display the area of forest lands within each of the damage classes for the entire Southeast Inventory District and for each of the individual counties within the district over the study period to further assess forest damage and recovery (Figure 4).
- Validation of the MODIS data products to estimate percent NDVI change was conducted by comparison to products based on similar techniques with higher spatial resolution Landsat 7 ETM+ NDVI products. The results of this validation effort are shown in Figure 6.
- The damage/disturbance products were also cross referenced with MIFI raster products indicating forest stand type (softwood, hardwood, or mixed) and stand age. This analysis (Table 2) indicates which types of trees were most heavily impacted by the hurricane event, useful information for timber managers to understand. Figure 5 is a map of forest types versus forest age.

CONCLUSIONS

Validation efforts support the technique of using MODIS-based NDVI percent change products to quantify the effect of Hurricane Katrina on coastal forests. Furthermore, this technique can extend to evaluations of other natural events to forested lands such as disease, fire, and other storm events. While the spatial resolution of MODIS may be too coarse for some applications, the reported approach can be used to enact more spatially directed timber inventories with ground sampling. Since ground sampling timber inventory activities can be costly, this MODIS-based approach can create significant cost savings by reducing man power and labor.

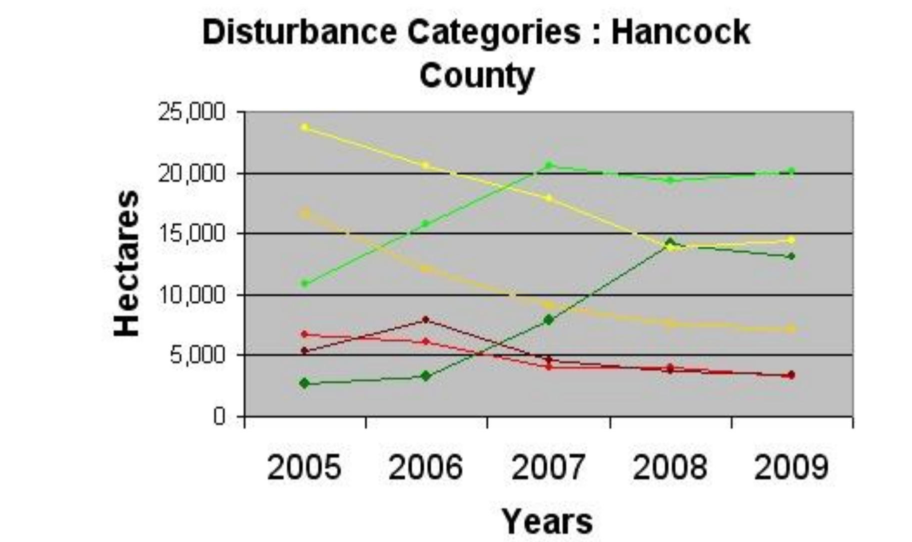

Figure 4: Measures of Window 15 disturbed area by damage class for Hancock County from 2005-2009 in hectares. Refer to Figure 2 for damage class legend.

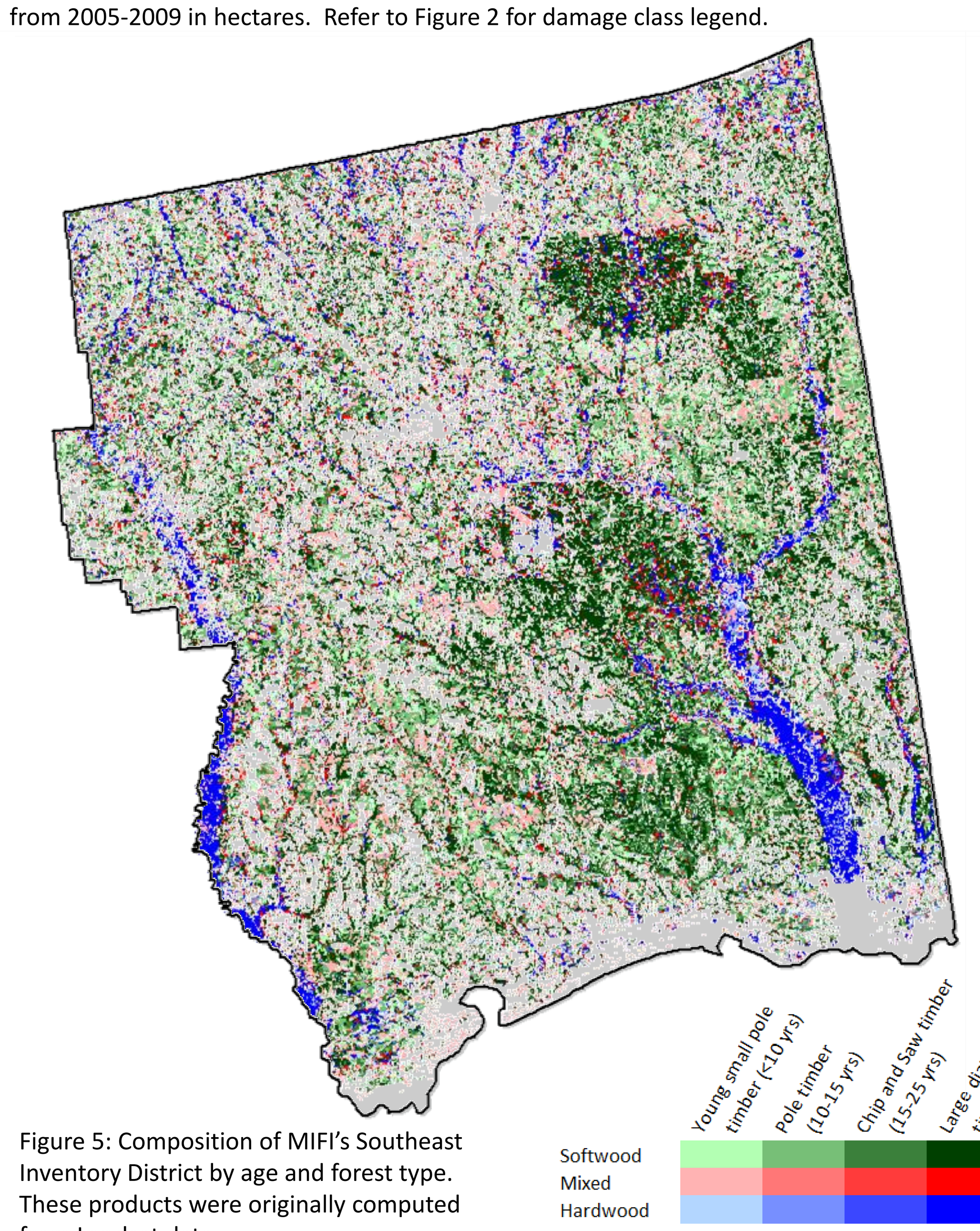

Figure 5: Composition of MIFI's Southeast Inventory District by age and forest type. These products were originally computed from Landsat data.

Damage Class	Age Class	Hectares	% of Total	% of Damage Class SubTotal
Class 1 (>= 0% NDVI Change)	Class 1: Less than 10 yrs	16688	2.22%	27.57%
	Class 2: 10 - 15 yrs	14056	1.87%	23.22%
	Class 3: 16 - 25 yrs	13125	1.75%	21.69%
	Class 4: Greater than 25 yrs	16656	2.22%	27.52%
Class 2 (0 to -5% NDVI Change)	Class 1: Less than 10 yrs	46075	6.14%	17.24%
	Class 2: 10 - 15 yrs	62219	8.29%	23.28%
	Class 3: 16 - 25 yrs	57225	7.63%	21.41%
	Class 4: Greater than 25 yrs	101756	13.56%	38.07%
Class 3 (-5 to -10% NDVI Change)	Class 1: Less than 10 yrs	33631	4.48%	12.05%
	Class 2: 10 - 15 yrs	62275	8.30%	22.31%
	Class 3: 16 - 25 yrs	63288	8.44%	22.67%
	Class 4: Greater than 25 yrs	119975	15.99%	42.98%
Class 4 (-10 to -15% NDVI Change)	Class 1: Less than 10 yrs	9556	1.27%	8.71%
	Class 2: 10 - 15 yrs	23481	3.13%	21.40%
	Class 3: 16 - 25 yrs	26031	3.47%	23.72%
	Class 4: Greater than 25 yrs	50681	6.75%	46.18%
Class 5 (-15 to -20% NDVI Change)	Class 1: Less than 10 yrs	2113	0.28%	8.54%
	Class 2: 10 - 15 yrs	5531	0.74%	22.35%
	Class 3: 16 - 25 yrs	6000	0.80%	24.25%
	Class 4: Greater than 25 yrs	11100	1.48%	44.86%
Class 6 (< -20% NDVI Change)	Class 1: Less than 10 yrs	800	0.11%	9.07%
	Class 2: 10 - 15 yrs	1994	0.27%	22.61%
	Class 3: 16 - 25 yrs	2188	0.29%	24.81%
	Class 4: Greater than 25 yrs	3838	0.51%	43.52%

Table 2: A comparison of the age characteristics and NDVI damage classes for all softwood trees in the Southeast Inventory District.

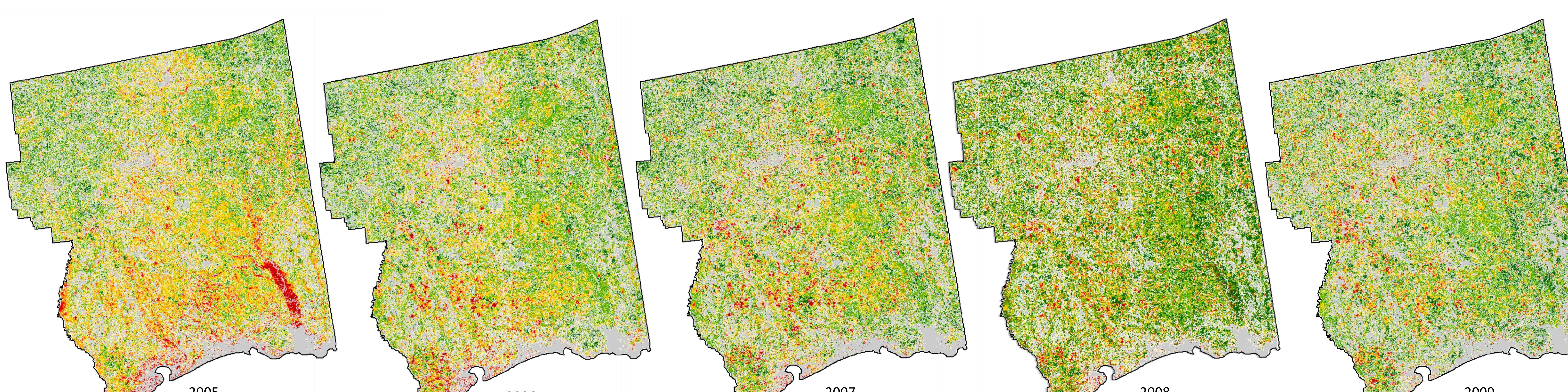

Figure 3: Side-by-side comparison of Window 15 NDVI percent change values. Each year is a comparison to the pre-Katrina baseline . This figure uses the same legend as Figure 2.

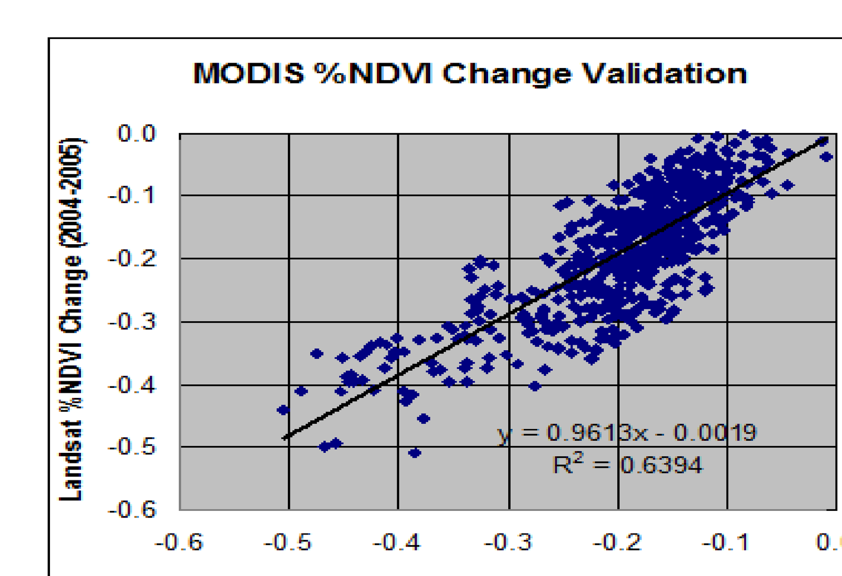

Figure 6: Validation scatter plot comparing MODIS with Landsat